Ioffe Institute
6th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 22–26, 1998.

Excitons in semiconductor quantum wires crystallized in transparent dielectric matrix

V. Dneprovskii†, T. Kobayashi‡, E. Mulyarov§, S. Tikhodeev§ and E. Zhukov†
† Physics Faculty, Moscow State University, 119899 Moscow
‡ Department of Physics, Tokyo University, Japan
§ Institute of General Physics, 117942 Moscow, Russia

Linear and nonlinear absorption of excitons with binding energies exceeding 100 meV has been observed at room temperature in GaAs, CdSe and InP quantum wires (QWRs) crystallized in transparent dielectric matrix (in crysotile asbestos nanotubes). The peculiarities of linear and nonlinear absorption have been explained by exciton transitions and by phase space filling of excitons in QWRs. The increase of the binding energy of excitons in QWRs arises no only due to quantum confinement but also due to dielectric enhancement of excitons [1].

As it is shown in [2]–[4] exciton transitions dominate in semiconductor QWRs — the abnormally strong concentration of oscillator strength becomes apparent at the frequencies of exciton transitions.

The existing methods of semiconductor QWRs fabrication do not allow to prepare samples with a suitable volume and density of nanostructures for optical absorption and nonlinear optical absorption measurements without application of a near field optical microscope. We have used the samples prepared by the method [5], [6] that allows to fabricate the samples with high density of QWRs. The molten semiconductor material was injected and crystallized in the hollow cylindrical channels of crysotile asbestos nanotubes. The measured diameter of this channels is 4.8 nm (for most of them) and 6 nm. The sample is a regular close packed structure of parallel crysotile asbestos transparent 30 nm diameter nanotubes filled with ultrathin crystalline GaAs, CdSe or InP wires.

The linear absorption spectra of QWRs crystallized in crysotile asbestos nanotubes are presented in Fig. 1. We attribute the absorption bands ("hills") of these spectra to exciton absorption in QWRs and the background to the absorption of the bulk semiconductor (part of the semiconductor material was crystallized between the nanotubes of crysotile asbestos). The measured energies of exciton transitions in QWRs (heavy hole–electron, light hole–electron excitons in GaAs and InP QWRs; the holes of A and B bands - electron excitons in CdSe QWRs) correspond to those calculated (arrows in Fig. 1) using a variational technique accounting for the effect of dielectric enhancement in the cylindrical QWRs. The calculated binding energies of excitons in QWRs surrounded by dielectric matrix (crysotile asbestos) exceed 100 meV.

The increase of the binding energies of excitons in QWRs crystallized in dielectric matrix compared to the bulk semiconductor, two-dimensional system and one-dimensional semiconductor surrounded by another semiconductor with nearly the same dielectric constant arises not only due to the quantum confinement but also due to the dielectric enhancement. The attraction between electron and hole becomes stronger because of the great difference in dielectric constants of semiconductor QWR and di-

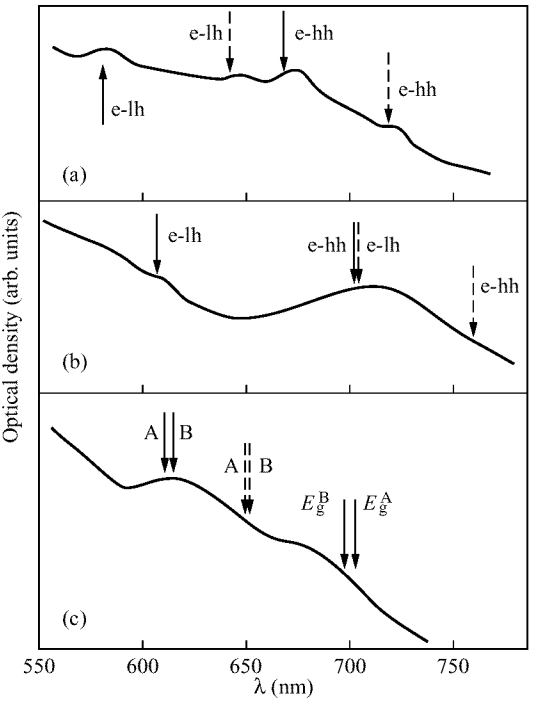

Fig 1. Linear absorption spectra for GaAs (a), InP (b) and CdSe (c) semiconductor quantum wires, crystallized in crysotile asbestos nanotubes. The calculated values of the energies of exciton transitions are shown by arrows for quantum wires with 4.8 nm diameter (full line) and 6 nm (dashed line).

electric matrix. The great broadening of exciton absorption bands arises probably due to the size dispersion of crystallized QWRs (inhomogeneous broadening).

Picosecond laser spectroscopy method (pump and probe technique — the measurement of differential transmission (DT) spectra using picosecond continuum as a probe beam) has been applied to investigate the physical processes leading to strong dynamic nonlinearities in semiconductor QWRs. It has allowed to exclude the background caused by the linear absorption of the bulk semiconductor and to distinguish the changes of transmission that arise in the case of high density of the excited excitons. The DT spectrum of CdSe QWRs crystallized in crysotile asbestos nanotubes is presented in Fig. 2 for different delay Δt between the pumping and probing pulses. Two bands of nonlinear absorption are strongly pronounced in DT spectra. We attribute the high energy band and its red shift at higher excitation to the saturation of the exciton transitions in CdSe QWRs and to the renormalization of the one-dimensional energy gap [7]. The bleaching of the low energy band and its blue shift may be attributed [8] to the Mott transition in the bulk CdSe (the vanishing of excitons due to the screening or phase space occupation) and gap shrinkage together with dominating band filling (Bursstein-Moss effect).

The dominant effect responsible for the observed bleaching of the exciton absorption in the investigated semiconductor QWRs has been revealed — phase space filling.

The great binding energies of excitons in QWRs crystallized in transparent dielectric,

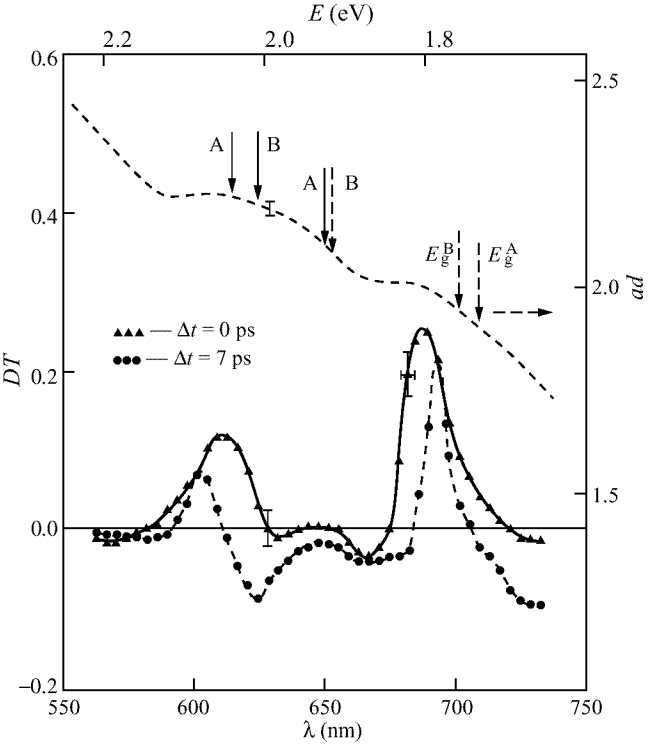

Fig 2. The linear and differential transmission spectra for CdSe quantum wires crystallized in crysotile asbestos nanotubes.

the possibility to change the energies of exciton transitions by changing the diameter of QWR, strong and fast exciton nonlinearity open new possibilities for the creation of "excitonic" optoelectronic devices that may operate at room temperatures.

This research was made possible in part by Grants 96-2-17339, 97-2-17600 of the Russian Foundation for Fundamental Research and Grants 97-1083, 97-1072 of the Russian Ministry of Science program "Physics of Solid Nanostructures". We thank V. Poborchii and S. Romanov for the samples of nanostructures crystallized in crysotile asbestos, N. Kisilev and D. Zaharov for the measurements with electron microscope.

References

[1] Mulyarov E. A. and Tikhodeev S. G. *JETP* **84** 151 (1997).
[2] Ogawa T. and Takagahara T. *Phys. Rev.* **B43** 14325 (1991).
[3] Ogawa T. and Takagahara T. *Phys. Rev.* **B44** 8138 (1991).
[4] Glutch S., Chemla D.S. *Phys. Rev.* **B53** 15902 (1996).
[5] Poborchii V. V., Ivanova M. S., Salamatina I. A. *Superlat. and Microstr.* **16** 133 (1994).
[6] Dneprovskii V., Gushina N., Pavlov O., Poborchii V. V., Salamatina I. and Zhukov E. *Phys. Lett.* **A 204** 59 (1995).
[7] Benner S. and Haug H. *Europhys. Lett.* **16** 579 (1991).
[8] Egorov V. D., Hoang Xuann Nguyen, Zimmermann R., Dneprovskii V. S., Kashke M. and Khechinashvili D. S. *phys. stat. sol. (b)* **159** 403 (1990).